Data-responsive Architectural Design Processes

Saleh Kalantari¹, Mona Ghandi²

¹,²Washington State University
¹,²{saleh.kalantari|mona.ghandi}@wsu.edu

Current advancements in information technology and mechanical components offer incredible new possibilities for innovation in architecture. Many aspects of our physical environment are becoming integrated with information systems, a phenomenon that has been referred to as the “Internet of Things.” The implications and applications of this technology are far-reaching, and students who are learning about design in today’s environment have a bewildering array of new tools available for their exploration. This paper reviews some of the central concepts of contemporary data-driven design, and describes how these concepts can be used in a pedagogical framework to encourage student innovation. The authors provide details about their work with students in IDR Studios, and highlight some of the innovative design solutions created by students using information-based toolsets. This research provides a pedagogical framework for helping design students to engage with new technological resources as they work to develop the architectural intelligence.

Keywords: Adaptive Systems, Internet of Things, Big Data, Data Driven Design Process

INTRODUCTION

The Internet of Things (IoT) is the name frequently given to environments in which wireless sensor networks, transceivers, and physical actuators merge with information systems, allowing the physical devices to respond to one another and to human participants, either directly or remotely. In other words, many parts of our physical environment are on the verge of becoming extensions of the Internet (Atzori et al. 2010; Gubbi et al. 2013; Vermesan & Friess 2014). The emerging IoT can be seen in many places, including homes, industrial workplaces, hospitals, energy grids, and traffic management systems (Bellavista et al. 2013). Urban services are a particular focus of growth for the IoT, due to the complexity of city environments—and also, perhaps, due to a push by national governments to more fully monitor and control public affairs. While a variety of policy-related concerns remain to be addressed in this area, it is undeniable that the IoT has much to offer humanity, including great improvements in efficiency in the areas of energy consumption, traffic congestion, industrial monitoring, waste management, and all kinds of city infrastructure use and operations. Taken together, this application of the IoT in civic infrastructure has been referred to as the rise of “smart cities” (Schaffers et al. 2011; Zanella et al. 2014).

In an ever-changing social world, the most congenial built environment is one that does not limit us and impose itself on our aspirations, but rather
has the capacity to change and respond to our needs in a fluid manner. Throughout its history architecture has evolved in this fashion, incorporating the latest technologies to better serve various social goals. In today’s world the pace of innovation is accelerating exponentially, making new technologies and materials available to the field. The use of these new technologies in architecture can be an important tool for meeting contemporary social challenges, making our lives more amiable, and reducing resource consumption. Real-time data gathering and analysis, in particular, allows us to automate routine tasks at both the micro- and macro-levels, improving the ease and effectiveness of our daily activities. These “smart environments,” when appropriately implemented, can make our lives more convenient. They also have the potential to be more flexible and responsive than traditional architecture, thereby expanding the range of our freedom and creativity (Batty et al. 2012).

This paper presents an overview of several areas in which architectural design can be usefully supplemented by contemporary data systems, building bridges between the world of information and the world of physical design. It also demonstrates the way in which such approaches to design are being integrated into pedagogical frameworks to help students explore their creative capacities within an ever-changing technological world. Everywhere around us today the informational and physical realms are becoming more interconnected. What is the role of the architect in this context?

ARCHITECTURAL DESIGN AND THE BIG-DATA CLOUD
The big-data revolution has influenced every aspect of a city life over the past two decades. However, smart cities are not merely the result of data collection; the quality of the urban environment resides mostly in how the data is used. Civil servants can implement systems that analyze, synthesize, and react to data as a means of improving social and economic services. The primary methods of collecting this data involve linking GPS information with satellite remote-sensing, smart phone applications, online social media networks, and interactive data systems focused on crowd-sourcing. The result is a rich field of opportunities to better understand how cities function (Batty et al. 2012). New data-driven techniques can allow for a rational and objective design process that achieves high-performance, efficient architecture tailored to a specific geographic context. As a result, the built environment becomes an active participant in the life of smart cities, drawing on data to respond to the needs of the city inhabitants. When architecture and urban design are driven by ongoing data collection in this manner, the result is a more flexible design process that grows and adapts to residents, much in the same way that a biological organism adapts to its local environment.

Sensors and cameras, digitally-controlled utility services, telecommunication networks, transportation infrastructure, and building management systems can also provide sources of information that can be monitored, analyzed, and fed back into the system to improve city services. When combined with information volunteered by individual residents, this “every-ware” data offers a more cohesive understanding of the city across multiple scales (Hancke & Hancke 2012; Townsend 2013). It can be used to evaluate existing conditions, to predict future outcomes, and to facilitate design and planning. At the same time that it improves the delivery of public services, the “every-ware” approach can also support greater public access, participation, and transparency (Allwinkle & Cruickshank 2011; Schaffers et al. 2011; Batty et al. 2012; Kitchin 2014).

The field of architecture has much to gain by drawing from developments in computer science, and in particular from the IoT approach. By incorporating interconnected sensing and actuating components in urban architecture, our designs become more responsive and gain the ability to share information as part of a unified smart-city framework. Eventually, the connection of data to the built environment will change the architectural design process into a data-driven field that better responds to hu-
A STUDIO FOCUSED ON ADAPTIVE SYSTEMS IN THE BIG-DATA ERA

The primary idea behind adaptive systems is to make architecture more responsive to the needs of its inhabitants in a day-to-day fashion. Adaptive systems have been used since the very beginnings of architecture; they can be as simple as doors and window-shutters, which allow the occupants to make adjustments to temperature and air-flow as needed. In the contemporary world architectural adaptability can also be incredibly sophisticated, as can be seen, for example, in the kinetic works of Santiago Calatrava (Millwakwe Art Museum 2001). The degree of adaptability in contemporary buildings varies widely according to the sophistication of the embedded machines. In general, however, recent years have seen an explosion in the prevalence of adaptive architectural systems, which has corresponded to the increasing practicality of artificial intelligence and active mechanical components.

Scholars have analyzed and categorized adaptive systems in a variety of ways. Fox and Yeh (1999), for example, classified kinetic architecture into “deployable,” “dynamic,” or “embedded” systems. These authors then also divided the means of adaptive manipulation into “internal control,” “direct control,” “indirect control,” “responsive indirect control,” “ubiquitous responsive indirect control,” and “heuristic responsive indirect control.” Ramzy and Fayed (2011) proposed an alternative categorization that organized adaptive systems based on the extent of their kineticism, their configuration, and the specific mechanical techniques used. What all of these commentators agree on is that adaptive systems are becoming increasingly important in today’s architecture, and that they have an important role to play in addressing social and ecological needs. Numerous scholars have called for research growth in developing new design methods and performance-based paradigms to support the spread of contemporary adaptive systems (Ramzy & Fayed 2011; Arenas & Falcón 2014; Kalantari 2016). The IoT and related computational technology merges seamlessly with the goals of adaptive architectural systems, providing tools that designers can use to enhance the environmental quality of buildings and promote more flexible, human-centered designs.

In a studio class that the authors have developed based around the use of adaptive systems, students explore methods of designing amid responsive environments in the era of big-data and informational-physical interconnectivity. Their journey starts with an immersion in scholarly literature and lectures about computational methods for information analysis. This instruction is combined with more traditional architectural education regarding the behavior of materials, fabrication, assembly, and so forth. In developing their projects, students make use of cutting-edge architectural software such as Grasshopper and Firefly, Python scripting, and a physical computing environment using Arduino microcontrollers. Students in the studio used these tools to design a new visitors’ center for their university, drawing strongly on the principles of adaptive systems and data-driven design. Examining the research process that these students went through demonstrates the exciting possibilities of designing amid the IoT.

Phase 1: Understanding the Internet of Things

The first part of the design process for students was to conduct a literature review to better understand contemporary outlooks on the IoT. The students were assigned to convey their understanding of the literature in the form of info-graphics (Figure 1).

Students engaged in the university visitors’ center project were divided into four groups for the purpose of conducting the literature review, with each group focusing on a separate topic:
• **IoT Smart City Applications.** Students in this group researched the concept of the smart city and the ways in which smart cities optimize resource-use, planning, and services. They learned about information exchange protocols and the integration of informational analysis with the physical components of the city, including transportation systems, utilities, and other major city components.

• **IoT Smart Building Envelope and Structural Applications.** Students in this group researched adaptive structures in the building envelope, and how these structures are becoming connected to information systems as part of the IoT. They examined case studies focusing on kinetic systems and climate-responsive design through different mechanisms such as operable roof systems, movable building flooring, and kinetic apertures (Sherbini & Krawczyk 2004; Gelpi 2013).

• **IoT Smart Space Applications.** Students in this group researched the integration of the IoT within interior building spaces, as a means of creating greater spatial flexibility, functional plurality, and performance quality. The use of the IoT in interior spaces can promote human interactions with the built environment as well as improving the overall occupant experience. The data-driven aspects of design become very important in this context, and allow for a better understanding of human behaviors and needs in interior building spaces.

• **IoT Building Automation Applications.** Students in this group researched how the integration of IoT applications into building systems can allow facility managers to more effectively and proactively maintain buildings at peak operational efficiency. They learned about the use of sensors and automation that allow smart buildings to improve in energy efficiency even while providing more comfortable and productive conditions for occupants. The students examined the different needs and technological solutions that go into the operational management of smart buildings, and investigated how individual buildings are beginning to be seen as a part of a much larger city system through greater informational connectivity.

---

**Phase 2: Exploring Adaptive Systems**

In the second part of the design process the students began to experiment with physical spaces, observing how built environments can be designed to gradually change based on various environmental and user inputs. They designed and fabricated a kinetic mechanism to explore the operation of adaptive sys-
tems, and they investigated how naturally occurring adaptive systems can serve as the inspiration for programmable built environments. A knowledge of material behavior and transformable, foldable, and deployable systems was vital in this exploration. The students were required to consider how their designs would change over time, and to incorporate activators such as heat, humidity, light, and motion. They made use of computational modeling in their explorations, as well as technologies such as 3D-printing, laser cutting, CNC routing, plasma cutting, and vacuum forming. During this phase the students also had the opportunity to collaborate with the members of the university’s Robotics Club to learn more about the use of micro-controllers. Many of the students had no previous experience with these topics, which resulted in a wide variety of unique and creative innovations as they gained vital practical knowledge in the field (Figure 2 & 3).

The motion-tracking system allows users to interact intuitively with the built environment, adjusting factors such as light-opacity and the direction of air-flow through either intentional gestures or passive environmental responses to the human presence.
Phase 3: Creating Data-Based Scenarios

Using the knowledge gained through their previous explorations, students in the studio went on to produce designs for a new university visitors’ center. These designs drew strongly from data-based scenarios and made use of adaptive system concepts. The resulting solutions show a strong effort to integrate the informational and physical environments. Students were instructed to design the building as a component of a smart city, and to incorporate elements that can respond to a wide array of data (including individual information volunteered through Internet-based media, city data such as demographic information and transportation schedules, and “machine-to-machine” data derived from sensors and related devices). Participating in a data-driven design process allowed the students to develop scenarios through which their adaptive building designs would react to the environment and to human inputs. As can be seen in the following examples, the design solutions created by the students focused on very different aspects of data-driven design. They are indicative of the wide array of creative innovation that is possible through the use of information technology.

The KINETICANOPY Project. This building is aware of the constant fluctuation of population and climate. Using real-time data to inform and reshape the structure and skin of the building, this new addition to the university campus is able to accommodate a variety of event types and sizes, while also adapting to the ever-changing urban conditions of pedestrian circulation. Using a hydraulic piston system, the columns and beams of the building work as a cohesive network with the ability to move in multiple vectors, allowing for different possibilities of form and function. At the same time, a building facade composed of rotating panels has the ability to respond to ever-changing weather patterns and occupant circulation. The facade provides shade and shelter from the elements while also becoming a kind of interactive display as it adjusts to the environment and the movement of the building’s occupants. Incorporating weather and population data into its calculations, the space continuously changes to suit the users’ needs.

While much of contemporary architecture incorporates a biomimetic component in looking to nature for its form-making inspirations, the impact of this approach is often limited to formalism. Kineticanopy’s exploration of bio-kinetics allow the architectural appreciation of nature to move beyond mimicry and to incorporate the changing natural environment in an ongoing, multi-directional interaction. The building also comes with its own app, a software program that can be downloaded to allow users to provide input into the lighting, shading, and spatial orientation to better suit their needs. The app includes a calendar and event-planning program that provides notifications about planned uses of the space, indicating any possible clashes. The app also incorporates information about nearby walking, biking, and driving routes and the features of the surrounding district and local businesses.

The new building will act as a gateway of expansion between the university district and the growing residential area surrounding it, allowing visitors, students, and the general populace to share ideas and create stronger connections with their environment. For the purposes of architectural development, Kineticanopy demonstrates a number of promising new concepts including transparency, large active deformation, and homogenous surfaces. The use of an electro-mechanical system connected to sensors allows for automated adaptation based on occupancy or predefined configurations. Interior spaces of the structure could also incorporate adaptive structures, including partitions, furniture, and other transformable elements that respond to user inputs (Figure 4).

The TENSILIBILITY Project. This building is an adaptive structure that adjusts to its users’ needs based on real-time environmental and human data. The entire structure expands and contracts so that it is more energy-efficient when its full expanse is not needed. By processing information supplied by its
users and the surrounding environment, the building, as an active agent decides how to best adjust its walls, structure, openings, exteriors, and interiors. The design incorporates curvilinear-oval and curved-triangle patterns that are reflective of the surrounding environment and nearby river. These elements of the surroundings are also made visible through the generous use of glass construction. The furnishings are curvilinear as well, and are designed to be moveable to accommodate the changing form of the structure. The interior spaces respond primarily to human activities and input, whereas the exterior form responds primarily to environmental conditions, including the temperature, time of day, and weather. The structure creates a visually and intellectually compelling mixed-use space that meets all zoning requirements and encourages visitors to engage with students and the local community. While the ground floor is oriented according to the city grid, the upper floor’s primary alignment is to local wind patterns, allowing for natural ventilation (Figure 5 & 6).

The GREEN VISITOR CENTER Project. This is an adaptive building that responds to solar radiation, human activity, and contemporary energy needs. It interactively connects the history of the
site to a forward-looking and inspirational environmental ethic. The preservation of history is expressed through permanent gallery installations that help visitors learn about the natural and human setting that they are a part of, including the vision of the facility and its use of reclaimed materials. The environmental ethic is also expressed by incorporating an eco-space and natural light-well within the heart of the building, allowing students and visitors to interact and relax in contact with nature.

The green structure is remarkable in that it makes use of an adaptive system based around the benefits of algae, primarily as a source of renewable energy. The algae are incorporated into the building design as an organic mesh over the exterior surface of the building, as well in other locations, where they serve as energy producers, as a form of interactive sculpture, and as an interactive informational installation. The algae absorb sunlight and carbon dioxide, while producing energy, oxygen, fertilizer, and food. They even help to clean the nearby river, as its water is circulated through the building to support the algae ecology. This building looks to nature not only as an inspiration for a static ideal of beauty, but also an integral and continuing process in the built environment.

The building’s form is made up of a hydraulic truss system that responds to solar data, curling downward and inward to create a cozier enclosure during poor weather, and curling upward and outward to provide more space and collect additional sunrays during pleasant weather. The truss will also respond to human input so as to create a more open or closed environment when necessary for programmatic reasons. The form of the building and the surrounding algae skin are purposely contrasting, as a symbol of the conflicted balance between humans and our environment. The algae skin appears to be engulfing the building, while the truss system pokes through the skin as though fighting back. In reality, however, the relationship is symbiotic in that the algae are providing power for the building, and the building gives structure and purpose to the algae cycle (Figure 7 & 8).

CONCLUSION AND FUTURE WORK

The Internet of Things can be understood as a seamless combination of data-driven design and adaptive systems. By showcasing the application of data-driven design strategies within a pedagogical context, this paper indicates some of the exciting innovations in architecture made possible by our current technological environment. The field of architecture has much to gain by drawing from developments in computer science and other related fields. As the interface between information systems and the physical environment continues to become more sophisticated, the prospects for innovation will only increase.

The educational approach described in this paper can be seen as a framework for integrating adaptive systems and data-driven approaches into a de-
Figure 7
The Green Visitor Center automatically adapts its configuration based on radiation analysis to absorb the maximum sunlight for algae growth.

Figure 8
The building's form is made up of a hydraulic truss system that responds to solar data.
sign studio and thereby unleashing students’ creativity to innovate with cutting-edge technological tools. The framework starts by introducing students to the relevant ideas in computational design, fabrication, information analysis, and responsive systems operations, and then builds on this basis through practical experimentation and design. In taking this approach, students become part of a new paradigm in which “architectural design” is not limited to the physical environment, but is rather understood as an interaction between the informational and physical realms. This allows our design to more fully account for all aspects of the human experience and human needs.

The outcome of this ongoing research is a platform for designers to study and create amid the new possibilities of architecture in the current technological moment. Instead of suggesting an ultimate solution for kinetic architecture needs, this research provides a proposed method that serves as a stepping-stone to endless design discoveries. Our studio on contemporary adaptive design in the era of big data incorporates multiple disciplines in a collaborative goal-driven environment, encouraging designers and researchers to reinterpret architecture as a way of working amid the Internet of Things. Students are at the forefront of this process, as they learn to evaluate and analyze data-driven design potentials in order to create smarter environments for the future. The authors of this paper are excited to continue forward on this pedagogical path to see what our future holds.

REFERENCES


Sherbini, K and Krawczyk, R 2004 ‘Overview of intelligent architecture’, *Proceedings of First ASCAAD International Conference*, Dhahran, Saudi Arabia


